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Climatic and structural comparison of yellow pine and mixed-conifer forests in northern Baja California (México) and the eastern Sierra Nevada (California, USA)

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ABSTRACT

Effects of fire suppression policies on semi-arid yellow pine and mixed conifer (YPMC) forests in the western US have been well documented, and restoration of forest structure and natural fire regimes are high management priorities to ensure the health and resilience of such forests. However, determining reference conditions for ecological restoration is difficult due to the near absence of undegraded forests in the US. YPMC forests of the Sierra de San Pedro Mártir (SSPM) in northern Baja California, Mexico, are highly similar to forests of the Eastern Sierra Nevada, California, USA, have experienced little to no logging, and until relatively recently supported a natural fire regime. As such, these Mexican YPMC forests are thought by many to represent reference ecosystems for restoration and resource and fire management in the US. However, to this point there has been no direct climatic comparison to determine to what extent SSPM is validly compared to California YPMC sites, nor a direct statistical comparison of forest conditions to see in what ways northern California forests might differ from SSPM. We compared climatic data from SSPM with 17 meteorological stations in the range of Jeffrey pine in Alta and Baja California. Based on this comparison, we determine that SSPM clearly belongs to the general class of Jeffrey pine-dominated YPMC forests found along the eastern edge of the California Floristic Province. We used field sampling to measure forest structure, fuels, and vegetation and ground cover in SSPM and in multiple National Forests along the eastern slope of the Sierra Nevada. Live tree density was nearly twice as high in the eastern Sierra Nevada as in SSPM, and dead tree density was 2.6 times higher. Basal area was about 30% higher in the eastern Sierra Nevada, even though average tree size was larger in SSPM. Fuel loads and coarse woody debris were very similar between the two sites, and fine fuels (1-hour fuels) were actually higher in SSPM. Logging and fire suppression have resulted in denser YPMC forests dominated by smaller trees in the US, but our results suggest that fire suppression in SSPM over the last 30 years has increased fuel loads. Nonetheless, the Baja California forests still retain an overstory structure created and maintained by centuries of frequent fire. This study provides important reference information for the management of eastern Sierra Nevada forests, and indicates that continued full fire suppression in SSPM carries significant ecological risks.

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1. Introduction

Most semi-arid forests in the western United States have been greatly affected by human management over the last 150 years, including resource extraction (timber harvest, grazing, mining, hunting), fire exclusion, and land development (Agee, 1993; Sugihara et al., 2006; Barbour et al., 2007). Timber harvest and fire exclusion have had the most significant broad-scale impact on the forests themselves, with the former removing most large trees and the latter removing the most important ecological disturbance process. In concert, logging and fire exclusion have notably simplified forest structure and had major impacts on forest species composition and ecological function (Parsons and DeBenedetti, 1979; Skinner and Chang, 1996; Sugihara et al., 2006; Mallek et al., 2013; Dolanc et al., 2014).

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In California, USA (hereafter "Alta California"), outcomes of past Euroamerican management have included forest stand densification and an increase in surface and ladder fuels (Sugihara et al., 2006). Successful fire exclusion policies implemented through most of the 20th century have resulted in the virtual absence of fire from large landscapes of yellow pine (*Pinus ponderosa*, *P. jeffreyi*) and mixed-conifer forest ecosystems ("YPMC" forests), ecosystems that experienced highly frequent, mostly low-severity fires before American settlement of Alta California began in the 1850s (Agee, 1993; Sugihara et al., 2006; Mallek et al., 2013; Safford and Stevens, in press). Many of these forests have now been subject to a 100 year fire-free period (Safford and Van de Water, 2014; Steel et al., 2015), which research suggests is unprecedented in at least the past 2000 years (Swetnam, 1993; Marlon et al., 2012). It is now well understood that the long-term lack of fire from YPMC forests is a major ecological perturbation in its own right. Recent increases in burned area, fire size, and fire severity in YPMC forests in some parts of Alta California and neighboring southwestern states appear to be the result of interactions between increasing fuels due to long-term fire suppression and the warming climate (Miller et al., 2009; Dillon et al., 2011; Miller and Safford, 2012; Mallek et al., 2013; Steel et al., 2015).

There is broad agreement that ecological restoration of western US forests should be a major focus of the federal resource agencies and other entities that manage large landscapes (Graber, 2003; USDA, 2006; SSP, 2010). At the same time, it is recognized that restoration is greatly complicated by the degraded condition of many western US forests, as well as by shifting environmental baselines caused by, among other things, global warming (Cole and Yung, 2010; Safford et al., 2012). Such issues are complications because ecological restoration traditionally relies on the identification of an undegraded reference state to guide management and to permit assessment of restoration progress (Egan and Howell, 2001). The degraded state of many modern western US forests means that contemporary reference landscapes are difficult to impossible to identify, which has resulted in a major focus on historical reference conditions (Morgan et al., 1994; Swetnam et al., 1999; Landres et al., 1999). However, the growing recognition that the changing climate, among other things, is altering the fundamental ecological conditions within which ecosystems exist is leading to fears – if sometimes exaggerated – that historical reference conditions may not provide sensible guidance if long-term sustainability is the ultimate management goal (Millar et al., 2007; Safford et al., 2012).

For researchers and managers in the southwestern US and Alta California, the less degraded condition of many nearby Mexican highland ecosystems has led to a developing recognition that the gold mine of contemporary reference landscapes may lie south of the border rather than north of it (Stephens and Fulé, 2005). Aldo Leopold may have been the first to appreciate the heuristic value of undegraded wildlands in northern Mexico to US resource management (Leopold, 1937; Leopold et al., 1947). Forest researchers in Arizona and New Mexico followed Leopold's lead and very important insights have been derived from comparative studies of southwestern US forests (mostly logged and fire-suppressed) and similar but less degraded forests in the Sierra Madre Occidental of northwestern mainland Mexico (e.g., Fulé and Covington, 1994, 1998; Meunier et al., 2014).

For Alta California, which mostly supports a different precipitation regime than the rest of the southwestern US, similarly less-degraded highland forests are found at the southern end of the California Floristic Province, in Baja California Norte. The 73,000 ha Sierra de San Pedro Mártir National Park (SSPM) is home to YPMC forests that have suffered neither long-term fire exclusion nor timber harvesting. Many researchers have recognized the floristic and ecological similarities between the SSPM forests and semi-arid YPMC forests in Alta California, and efforts have been made to draw management and restoration lessons from the conditions that exist in the SSPM. Scientific study in the SSPM has described, among other things, forest phytosociology (Peinado et al., 1997), phytogeography (Peinado et al., 1994a, 1994b), floristics (Passini et al., 1989; Thorne et al., 2010), forest structure and mortality (Stephens and Gill, 2005), fuel loads and snags (Stephens, 2004), post-fire regeneration (Stephens and Fry, 2005), spatial patterns of wildfire (Stephens et al., 2008), fire history (Minnich et al., 2000; Stephens et al., 2003; Evett et al., 2007a; Skinner et al., 2008), and forest disease (Maloney and Rizzo, 2002).

For US managers interested in YPMC forest and fire restoration in Alta California, these studies might potentially provide valuable reference information, however there are a few important limitations in this body of work. First of all, very few of the studies have carried out direct statistical comparisons between SSPM and Alta California forests. Exceptions include Savage (1997), who compared forest mortality after drought between SSPM and the San Bernardino Mountains in southern Alta California; and Fry et al. (2014), who compared spatial patterns in forest structure between two 4-ha stem-mapped plots in SSPM and two similar Jeffrey pine-mixed conifer plots in the southern Sierra Nevada, Alta California. Second, almost all of the detailed forest structural data we have from SSPM come from an array of permanent plots found in a small area of relatively homogenous terrain and forest; forest characteristics in different landscape positions and in other parts of SSPM have yet to be quantified through on-the-ground measurement. Third, to this point no one has carried out a rigorous comparative analysis of the climate of SSPM and the climates of YPMC sites in Alta California where SSPM-derived reference information might be applied. Without such an analysis, managers and restoration practitioners run the risk of employing SSPM reference conditions in locations were their use is not well justified.

The eastern slopes of the Sierra Nevada in Alta California support YPMC forests and landscapes that are remarkably similar to the SSPM (Fig. 1). Dominant tree species are mostly shared, the most common shrubs and herbs are congeners or conspecifics, geologic substrates are mostly granitic or metamorphic in both areas, and both are found on the continental margins of the North American Mediterranean climate zone, also known as the California Floristic Province. On the surface, the major differences appear to be the geographic location (SSPM is 500–1100 km to the south), and legacies of past and current human management, where most of the Sierra Nevada forests have experienced some level of timber harvest and a century or more of fire exclusion, and SSPM has not been logged and lacked effective fire suppression until the last three decades. However some authors have questioned whether climates are sufficiently similar between SSPM and Alta California sites to permit SSPM's use as a reference ecosystem (Keeley, 2006).

Because researchers have advocated use of SSPM reference information in YPMC forests in Alta California (e.g., Minnich et al., 1995, 2000; Stephens and Fulé, 2005), and because managers and restorationists in the eastern Sierra Nevada have already begun to use reference information from SSPM in resource management planning and project development (e.g., USDA, 2015), we resolved to carry out a study that directly compared forest structure and climate in the two areas. Our principal purposes were (1) to explore how, in the context of differing management histories, modern eastern Sierra Nevada YPMC forests compare structurally to similar forests in SSPM; and (2) to determine whether climates in the two areas (and other YPMC areas in Alta California with Jeffrey pine) are sufficiently similar to justify the application of SSPM reference information to restoration projects in the eastern Sierra Nevada.